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# THE DESIGN OF A 'JET CATCHER'

by

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SUMMARY

The basic principles of a device for catching and dissipating the kinetic energy of a jet are described and a design of a particular form of the jet catcher outlined. This has been in use for some time as part of the RAE Boundary Layer Tunnel and has proved completely successful in eliminating unwanted air currents in the test room of the tunnel.

The device should have wide applications in industry in general and in aeronautics in particular in situations where high energy jets may be a source of nuisance or even of danger. It has been patented under British Patent Specification 1490188.





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## 1 INTRODUCTION

The RAE Boundary Layer Tunnel is an open return facility driven by a 100hp ventilating fan. It is provided with interchangeable working sections of cross-section either 1.2 m x 0.3 m or 0.6 m x 0.6 m. There is no diffuser downstream of the working section which exhausts into the test room. The tunnel was designed in this way to avoid restrictions on the design of the working sections and also in order to be able to control the pressure in the working section by means of a screen over the exit. This control made it possible to bleed flow from the working section, for example, to avoid unwanted separations or to provide some special flow characteristic.

There was thus a problem of a jet of speed up to 50 m/s emerging into the test room. The jet not only produced unpleasant draughts and created unsteadiness in the pressure in the test room and unsteadiness in the tunnel flow but also could be a source of danger to the unwary operator. The device shown in Fig 1 and termed a 'jet catcher' was therefore installed to suppress the effects of the jet. It was remarkably successful and is considered to have other applications, in suppressing jets arising from discharge in industrial processes, and in reducing the effects of aircraft jet engines in ground running. It has been patented under British Patent Specification 1490188.

The principles of the design and the details of the device used in the Boundary Layer Tunnel are given.

## 2 PRINCIPLE OF OPERATION

The basis of the design can be seen most simply by applying actuator-disc theory to an isolated sheet providing an aerodynamic resistance. For the configuration shown in Fig 2 and with the notation shown there for an incompressible flow of density $\rho$ , Bernoulli's equation applied to the flow on each side of the screen gives

$$p_0 + \tfrac{1}{2}\rho v_0^2 = p_1 + \tfrac{1}{2}\rho v_1^2 \quad , \tag{1}$$

and

$$p_1' + \tfrac{1}{2}\rho v_1'^2 = p_0 + \tfrac{1}{2}\rho v_\infty^2 \quad , \tag{2}$$

with

$$v_1 = v_1' \quad \text{from continuity} \quad . \tag{3}$$

The pressure drop through the resistance is

$$p_1 - p_1' = \tfrac{1}{2}\rho v_1^2 k \quad , \tag{4}$$

where $k$ is the resistance coefficient, and the momentum balance across the resistance is

$$p_1 - p_1' = \rho v_1 (v_0 - v_\infty) \quad . \tag{5}$$

From these equations the velocities $v_1$ and $v_\infty$ can be expressed as

$$\frac{v_1}{v_0} = \frac{4}{4 + k} \quad , \tag{6}$$

and

$$\frac{v_\infty}{v_0} = \frac{4 - k}{4 + k} . \tag{7}$$

For $k = 4$, $v_\infty = 0$ so that on the basis of this simple model of the flow, the kinetic energy of a jet impinging on the resistance will be completely destroyed, that is converted into heat energy. The velocity through the resistance is half the jet velocity so that a resistance having an area twice that of the jet is required. The force per unit area on the resistance is from equations (4) and (6)

$$p_1 - p_1' = k\left(\frac{4}{4 + k}\right)^2 \tfrac{1}{2}\rho v_0^2 ,$$

giving a drag coefficient

$$C_D = k\left(\frac{4}{4 + k}\right)^2 . \tag{8}$$

For $k = 4$ the drag coefficient is unity, which for a resistance of area twice that of the jet implies, as it should, that the force on the resistance is equal to the jet momentum. Graham[1] has plotted measurements, from various sources, of the drag coefficient of porous plates placed normal to a uniform flow and shown that, for values of $k$ up to about 4, the results agree roughly with equation (8). Thus it may be concluded that a single resistance or screen set normal to the flow could be used to 'catch' a jet. However, the high resistance of the screen would certainly cause a substantial portion of the jet to turn along the face of the screen without any loss of total pressure. It was considered that this 'spillage' of the jet might be overcome if the catcher were to be dished so that the jet is first caught and must then pass through the screen losing kinetic energy in the process. It was therefore felt that a more satisfactory device could be made using the refractive property of an inclined screen in addition to the pressure drop and the diffusion of the flow caused by a screen placed normal to the flow. This led to the design shown in Fig 1 which combines, in a compact device, the required dished front face together with a large outlet area. The internal details follow from the very simple analysis given below.

## 3 A SPECIFIC DESIGN

Whilst the internal flow of the device may be calculated from considerations of the local flow only, calculation of the approach and exit flow requires an analysis similar to that for the single normal resistance. The internal flow of the rectangular configuration of Fig 1 is represented by the flow in a conical configuration. To simplify the problem of calculating the overall flow a sector of the flow is considered to be represented by a stream tube flowing through an inclined resistance as shown in Fig 3. The angle $\theta_1$ is given so that there are six unknowns $p_1$, $v_1$, $p_1'$, $v_1'$, $\theta_1'$, $v_\infty$ hence six equations are required. Three of these are equations (1), (2) and (4) already given; the remaining equations are the continuity of mass flow across the resistance,

$$v_1 \cos \theta_1 = v_1' \cos \theta_1' , \tag{9}$$

and the momentum balance normal to and parallel to the resistance

$$\rho v_1 \cos\theta_1 (v_0 \cos\theta_1 - v_\infty \cos\theta_1') = \tfrac{1}{2}\rho v_1^2 k \quad , \qquad (10)$$

$$\rho v_1 \cos\theta_1 (v_0 \sin\theta_1 - v_\infty \sin\theta_1') = \tfrac{1}{2}\rho v_1^2 F \quad , \qquad (11)$$

where $k$, $F$, the resistance coefficients normal to and parallel to the plane of the resistance, are functions of $\theta_1$.

The aim of the design is to reduce the exit velocity to zero, hence we take $v_\infty = 0$. Equations (1), (2), (4) and (8) then lead to

$$v_1^2\left[1 + k - \frac{\cos^2\theta_1}{\cos^2\theta_1'}\right] = v_0^2 \quad , \qquad (12)$$

and (10) becomes

$$2v_0 \cos^2\theta_1 = kv_1 \quad . \qquad (13)$$

Values of the velocity ratio $v_1/v_0$ and resistance coefficient $k$ evaluated from equations (12) and (13) are shown in Fig 4a&b for a range of values of $\theta_1$ and $\theta_1'$, and values of $F$ from equation (11) (with $v_\infty = 0$) are shown in Fig 4c. The values of $F$ required are considerably in excess of those for a single screen as determined by Schubauer et al[2]. Thus a multiple screen arrangement is required, and, in fact, it was concluded that a central cone or pyramid was required to produce a deflection additional to that produced by the screens. Plausible values of $\theta_1$ and $\theta_1'$ for the configuration of Fig 1 are $45^\circ$ and $0^\circ$ respectively, for which $v_1/v_0 = 0.732$ and $k = F = 1.366$. The internal flow was therefore calculated for an inlet velocity ratio $v_1/v_0 = 0.732$.

The notation for this calculation, which can only be regarded as approximate, is shown in Fig 5. It is assumed that the flow fills the jet catcher and is uniform through each of the screens, so that the continuity equation is

$$v_1 \cos\theta_1 A_1 = v_2 \cos\theta_2 A_2 = v_3 \cos\theta_3 A_3 \quad , \qquad (14)$$

where

$$\left.\begin{aligned} A_1 &= \pi r_0^2 \operatorname{cosec}\alpha_1 \quad , \\ A_2 &= \pi\left(r_0^2 - r_2^2\right) \operatorname{cosec}\alpha_2 \\ A_3 &= 2\pi r_0^2 (\cot\alpha_1 + \cot\gamma) \quad , \end{aligned}\right\} \qquad (15)$$

whilst across each screen

$$v_n \cos\theta_n = v_n' \cos\theta_n' \quad , \qquad n = 1,2,3 \quad . \qquad (16)$$

The pressure drop across each screen is

$$p_n - p_n' = \tfrac{1}{2}\rho v_n^2 k \quad , \qquad (17)$$

and the momentum equation parallel to a screen is

$$F = 2\cos^2\theta_n\,(\tan\theta_n - \tan\theta'_n) \quad , \tag{18}$$

where

$$k = k_0\cos^2\theta_n \quad , \tag{19}$$

and

$$F = \frac{3k\theta_n}{4 + k} \quad . \tag{20}$$

$\theta_2$ and $\theta_3$ are obtained by assuming that the flow between two screens aligns itself with the face of the central cone before entering the downstream screen.

In equation (19) $k_0$ is the resistance coefficient of a screen mounted normal to the flow. Equations (19) and (20) are derived from Schubauer et al[2], equation (20) being a modified form of their empirical equation.

The final outlet velocity is found from the total pressure

$$\tfrac{1}{2}\rho v_\infty^2 = H_\infty - p_0 = H_0 - p_0 - \Sigma\Delta p_n - \Sigma\tfrac{1}{2}\rho v_n^2 + \Sigma\tfrac{1}{2}\rho (v'_n)^2 \quad . \tag{21}$$

Application of these equations to the design of Fig 5 with the following values of the parameters,

$$\alpha_1 = 45^\circ \qquad \alpha_2 = 18.4^\circ \qquad \gamma = 45^\circ \qquad k_0 = 2 \quad ,$$

gives the results shown in Table 1, in which the velocities are normalised by the jet velocity and the pressure drop by the jet kinetic pressure.

Table 1

| Screen | 1 | 2 | 3 |
|---|---|---|---|
| $v_n$ | 0.732 | 0.345 | 0.250 |
| $v'_n$ | 0.606 | 0.318 | 0.207 |
| $\theta_n$ | 45 | 26.6 | 45 |
| $\theta'_n$ | 31.3 | 14.1 | 31.3 |
| $\Delta p$ | 0.536 | 0.094 | 0.054 |
| $v_\infty^2/v_0^2$ | 0.016 | | |

The calculation thus predicts a final outlet velocity of about $\frac{1}{8}$ of the jet velocity. In fact it was found that the jet catcher spilled some of the jet flow, so that it may be surmised that the pressure losses were rather greater than calculated. The spillage was eliminated by providing the leak through the centre of the first screen shown in Fig 1. A further modification was also made. The impingement of the jet on the first screen

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created some noise. This was eliminated by tacking a muslin screen over the first wire-gauge screen. With these modifications the jet catcher worked in a completely satisfactory manner with the emerging flow being virtually undetectable.

## 4 CONCLUDING REMARKS

The basic principles of a device for catching and dissipating the kinetic energy of a jet have been described and the design of a particular form of the jet catcher outlined. This has been in use for some time as part of the RAE Boundary Layer Tunnel and has proved completely satisfactory in eliminating unwanted air currents in the test room of the tunnel.

The design method is far from being rigorous but the design appears to be rather forgiving and will work well even if not precisely with the flow postulated.

The jet catcher should have applications in industry in general and in aeronautics in particular in situations where high energy jets may be a source of nuisance or of danger.

## LIST OF SYMBOLS

| | |
|---|---|
| $A$ | area of screen |
| $F$ | tangential resistance coefficient of screen |
| $H_0$ | inlet total head |
| $H_\infty$ | exit total head |
| $k$ | normal resistance coefficient of screen |
| $k_0$ | value of $k$ for flow incident normally |
| $p$ | pressure |
| $\Delta p$ | pressure drop |
| $r_0$ | radius of jet catcher |
| $r_2$ | radius of downstream end of second screen |
| $v$ | velocity |
| $v_\infty$ | exit velocity at infinity |
| $\alpha$ | inclination of screen to axis |
| $\gamma$ | inclination of centre-body to axis |

For further details see Figs 2, 3 and 5.

## REFERENCES


| No. | Author | Title, etc |
|---|---|---|
| 1 | J.M.R. Graham | Turbulent flow past a porous plate. J Fluid Mech, 73, 3, 565-591 (1976) |
| 2 | G.B. Schubauer<br>W.G. Spangenberg<br>P.S. Klebanoff | Aerodynamic characteristics of damping screens. NACA TN 2001 (1950) |

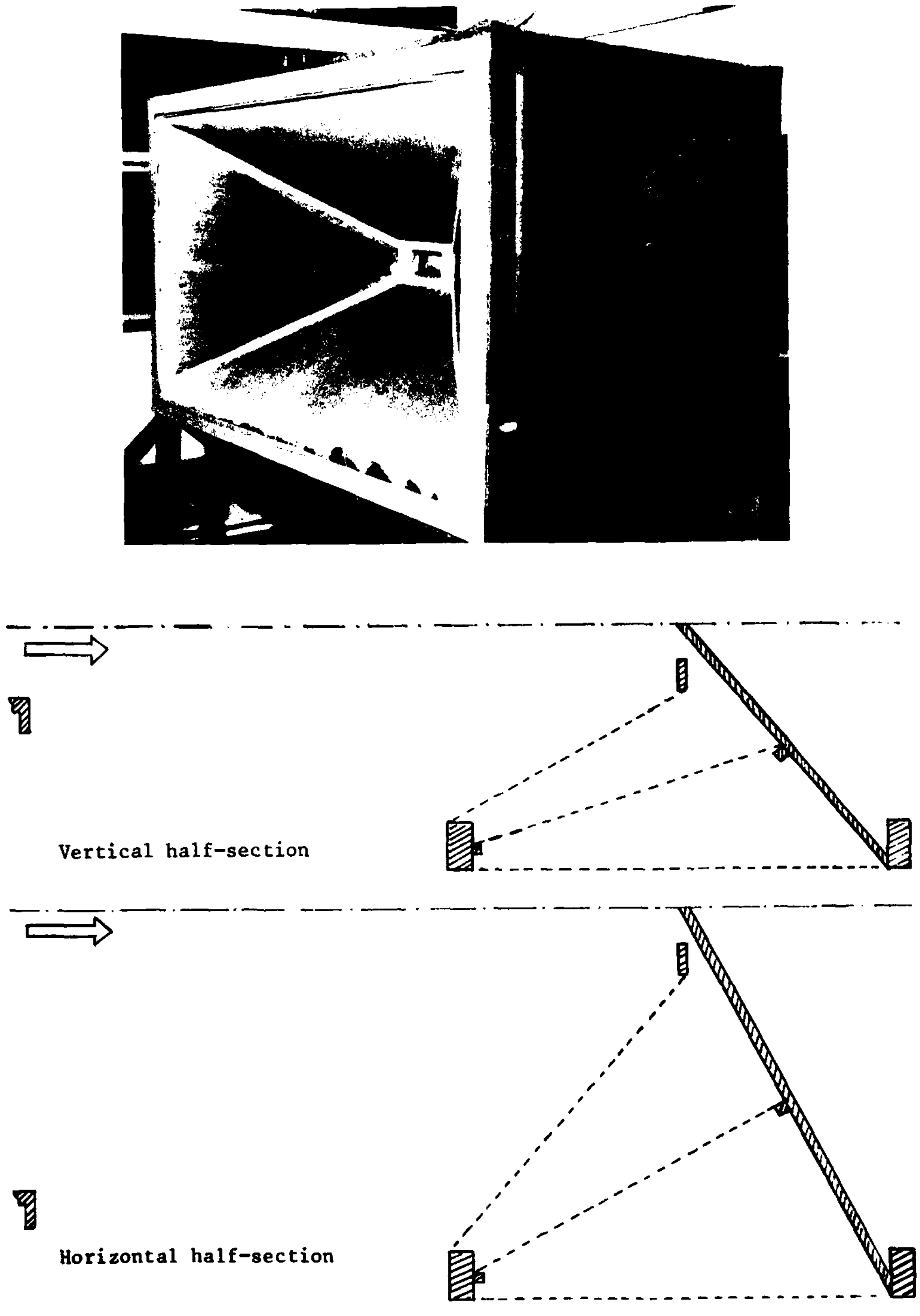


Fig 1 Jet catcher used with boundary layer tunnel

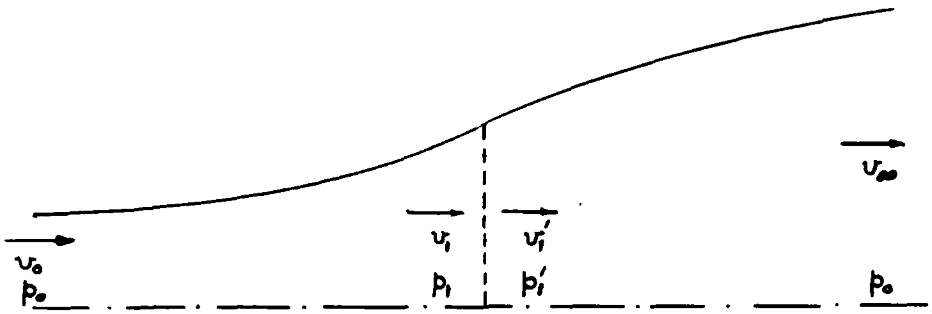


Fig 2 Resistance set normal to flow

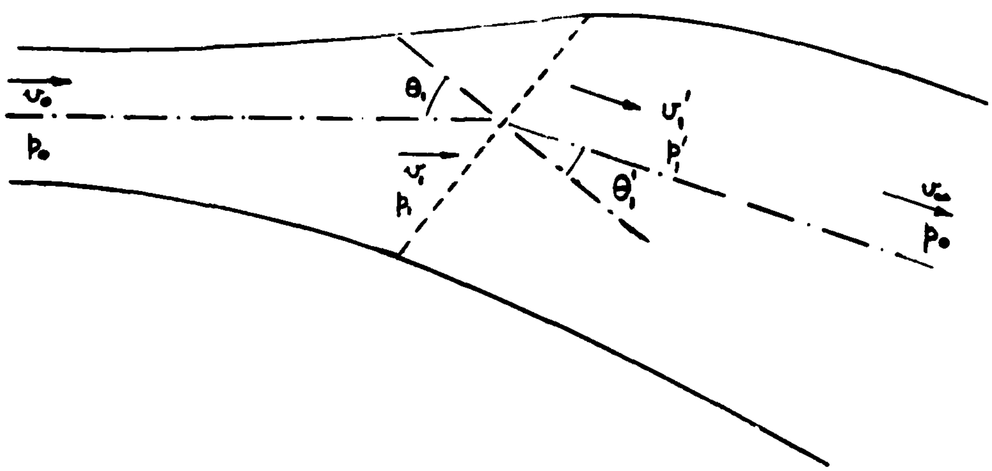


**Fig 3 Inclined resistance**

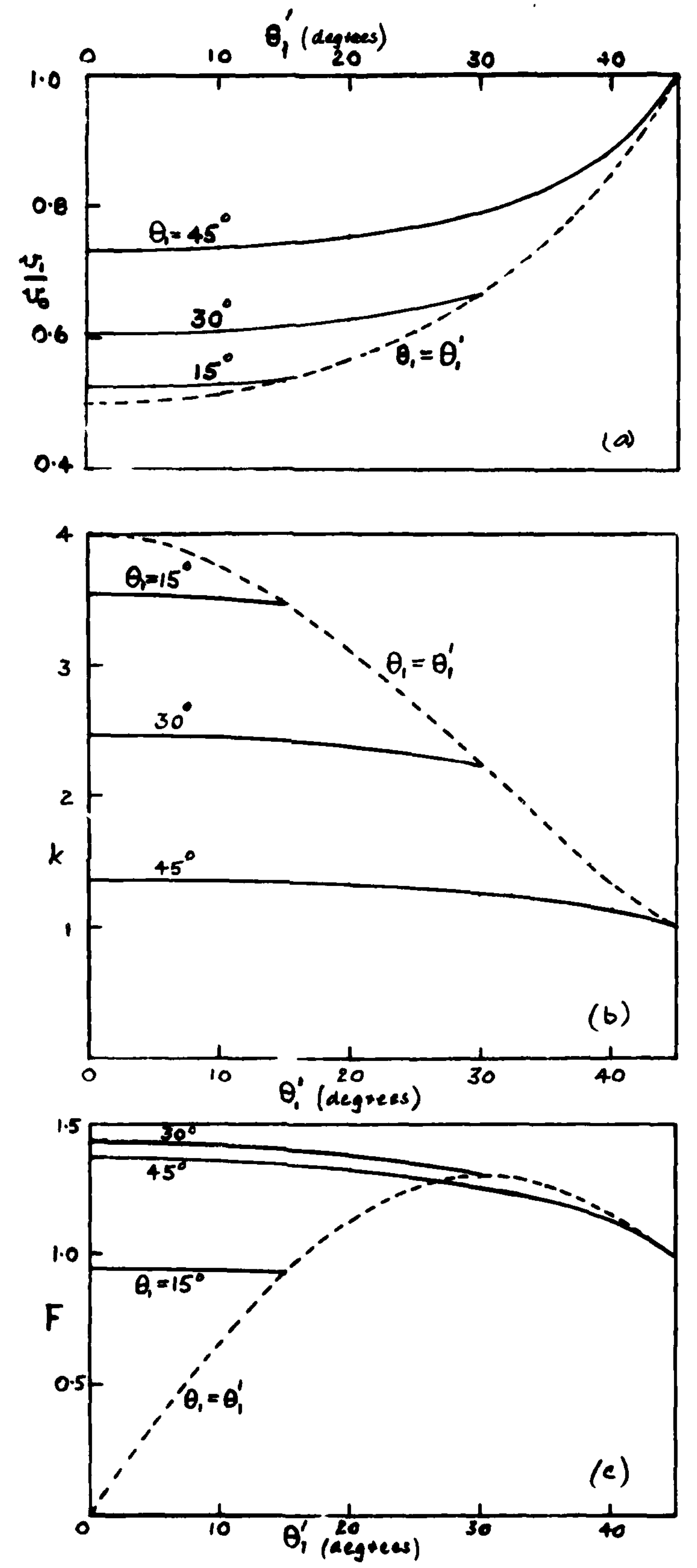


Fig 4 Values of 'inlet' velocity ratio and resistance coefficients for inclined resistance

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17. Abstract


The basic principles of a device for catching and dissipating the kinetic energy of a jet are described and a design of a particular form of the jet catcher outlined. This has been in use for some time as part of the RAE Boundary Layer Tunnel and has proved completely successful in eliminating unwanted air currents in the test room of the tunnel.

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